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RELIABILITY ASSESSMENT OF THE POWER SUPPLY FOR THE CLARKSON SYSTEM CONTROL CENTER

Report No. 88-304-K

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ABSTRACT

A reliability assessment of the power supply for the new system control center at Clarkson has been carried out. The mean times between failures, the mean times to restore service and the probabilities of interruption of power supply at various load points in the control center have been estimated and are used as the reliability indices. These values were examined by personnel from the relocation project team and judged to be acceptable.

1. INTRODUCTION

Ontario Hydro plans to move the System Control Center (SCC) to a new location at Clarkson by the year 1991. The Operations Research Department is taking part in the reliability evaluation of the new facilities. The current study forms a part of the investigation and examines the reliability of the power supply to the Control Center. This report summarizes the results of the assessment.

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2. THE SYSTEM

2.1 Description

Power to Clarkson SCC from the Bulk Electricity System (BES) is supplied by two separate 28kV/4.16kV transformers via the feeders M4 from Lorne Park TS and M13 from Oakville TS. The location of these feeders in the BES is shown in Figure 1. A simplified one-line diagram of the supply at Clarkson is shown in Figure 2.

For the purposes of the current study, the power supply at Clarkson can be divided into the following groups:

- Class IV supplying all non-critical loads (including office loads).
- Class III feeding essential loads including the primary feeds to the air-conditioning system, control room lighting etc.
- Class II which consists of five uninterruptible power supply (UPS) systems and feeds all critical loads, including the Data Acquisition and Computer System (DACS). This group can be further divided into four subgroups:
  - computer room loads supplied primarily by UPS A and UPS B
  - control room loads supplied by UPS A and UPS B
  - the DACS support systems supplied primarily by UPS C
  - loads supplied by UPS D and UPS E, e.g., power to the circuit breakers.

The 4.16kV supply is stepped down to 600V at two Class IV substations and at two Class III substations. Two cross-ties, one at the 4.16kV level and the other at 600V, are available at the Class IV level. At the Class III level, two diesel generators are available as backups and can assume load in one minute.

Class III power also supplies the UPS systems providing the Class II supply. UPS A, UPS B and UPS C operate at 600V whereas UPS D and UPS E operate at 120/208V supplied by two 600/120/208V transformers fed by two separate Class III feeds. Figure 3 illustrates the details of the UPS A system. Under normal conditions, the AC power is converted to 400V DC by the rectifier and the filtered AC output of the inverter supplies the load. A 400V battery system with a 30-minute capacity is available as back-up if the primary AC power is lost or if the rectifier fails. Note that under most contingencies, the battery system will be required only for a minute or so, ie, until the diesel generators at the Class III level assume load. If the inverter fails, the high speed static switch triggers and the supply is automatically switched over to an alternative source (to UPS C or to a class III source).

This study evaluates the reliability levels of power supply to the above loads as well as at some intermediate points. These points are identified in Figure 2 by the labels *T1*, *T2* ... *T11* and are defined in Subsection 2.2. The definitions are followed by failure criteria for the load points in Subsection 2.3.

2.2 Load Points

As mentioned earlier, two Class IV substations provide power to most non-essential loads at Clarkson. A feed from one of the substations is labeled as load point *T1*. Two cross-ties are available at the Class IV level to ensure continuity of supply. The 4.16kV tie is expected to close in 5 seconds and the 600V tie in 10 seconds. Two Class III substations supply some essential loads such as air conditioning. Load point *T2* is a load supplied by one of the Class III substations and load point *T3* is a load supplied by both the substations. Two standby diesel generators, which start up when both the main feeds fail, serve as backups at this level and are expected to assume load in about 1 minute. Each diesel generator is capable of handling the entire Class III load at Clarkson, in case the other becomes unavailable. A cross tie is available for use when either diesel generator fails.

The output of a UPS and a manual bypass from Class III feed into a metalclad switchgear and three such metalclad switchgears (UPS A, UPS B and UPS C) feed the DACS system. The output of the UPS A switchgear is designated as load point *T4*. The outputs from the UPS A and UPS B switchgears together (two feeds each) supply the computer room via two separate computer distribution frames. The control room is supplied by two feeds, one each from UPS A and UPS B via the two distribution frames mentioned above. UPS C metalclad switchgear supplies the DACS support system (three feeds) via another computer distribution frame. UPS C also serves as a further level of backup for UPS A and UPS B at the input to the computer distribution frame (after a manual switching). The input to a two computer distribution frame feeding the computer and control rooms is termed load point *T5*.

Load point *T6* is defined as any one of the 4 feeds supplying the computer room and load point *T7* refers to two of the four feeds, one each from the two distribution frames. Load point *T8* is defined as any one of the two feeds to the control room and both the feeds together are labeled as load point *T9*. Load point *T10* refers to any one of the 3 feeds supplying the DACS support system. UPS D and UPS E supply most of the critical control power via two computer distribution frames. The output of the UPS D (or UPS E) computer distribution frame is termed load point *T11*.

2.3 Failure Criteria for the Load Points

T1 Loss of power to a load supplied by a feed from a Class IV substation.
T2 Loss of power to a load supplied by a feed from a Class III substation.
T3 Loss of power to a load supplied by feeds from both Class III substations.
T4 Loss of power at the output of the UPS A switchgear.
T5 Loss of power at the input to a computer distribution frame feeding the computer and control rooms.
T6 Loss of any one of the four feeds to the computer room.
T7 Loss of two of the four feeds to the computer room, the two feeds in question being fed via two separate computer distribution frames.
T8 Loss of any one of the two feeds to the control room.
T9 Loss of both the feeds to the control room.
T10 Loss of any one of the three feeds to the DACS support system.
T11 Loss of power at the output of UPS D (or UPS E) computer distribution frame.

3. RELIABILITY EVALUATION

In this study, the mean times between failures, the mean times to restore service, and the probabilities of interruption of power supply to the load points listed in Section 2 are used as indices of reliability of power supply to the System Control Center. The main step in the reliability evaluation is a failure mode and effect analysis /1/.

3.1 Assumptions

- The individual events causing the outages are independent, although some of the events may cause the removal of more than one component from service.
- Overloads and voltage criteria are not considered.
- After a forced outage, the component is isolated by switching.
- Only single and double contingencies are considered.
- Maintenance events (scheduled outages) occur randomly, except that an event is postponed if it would cause a supply interruption.

3.2 Outages considered

- Independent outages of major components. These include:
  - Transmission circuits,
  - Distribution feeders,
  - Circuit breakers,
  - Line terminals,
  - Bus sections,
  - Transformers,
  - Computer distribution frame bus sections,
  - Computer distribution frame breakers,
  - UPS rectifiers,
  - UPS inverters,
  - UPS batteries
- Common mode outages of transmission circuits on common towers
- Failures of breakers to operate when required
- Generator failures

It should be borne in mind that the study does not include the impact of an event such as a fire in the building which might take out several components at once. Such an event will have a significant impact on the computed indices, but the probability of such an event is difficult to assess. Component outage data used in this study are obtained from References 2,3 and 4 and are listed in Appendix A.

3.3 Results

The results of the reliability analysis are presented in Tables 1 to 11 for load points *T1* to *T11* respectively. In the Tables, the results are divided into outages caused by forced outages alone, and outages involving maintenance, ie, outages caused by a forced outage of a backup during a maintenance outage. It should be noted that if the maintenance of a component causes an immediate outage at any of the load points, then this event is not included in the results for that load point, but is included in all 'downstream' calculations. For example, the maintenance of UPS A switchgear causes an immediate outage at load point *T4* and Table 4 does not reflect the impact of this event. However, this maintenance event does affect load point *T6* and the impact is included in the results for load point *T6* in Table 6. A summary of the results is given below.

Load Point	MTBF (years)	Mean Time to Restore	Probability of Outage
T1	2.13	1.46 hrs	$78.5 * 10^{-6}$
T2	208	8.00 hrs	$4.39 * 10^{-6}$
T3	200,000	4.00 hrs	$2.02 * 10^{-9}$
T4	75.4	7.62 hrs	$11.5 * 10^{-6}$
T5	75.3	10.6 min	$0.267 * 10^{-6}$
T6	18.3	12.8 hrs	$79.8 * 10^{-6}$
T7	500,000	3.76 hrs	$0.854 * 10^{-9}$
T8	23.9	8.65 hrs	$41.3 * 10^{-6}$
T9	1,000,000	3.66 hrs	$0.429 * 10^{-9}$
T10	26.0	17.0 hrs	$74.8 * 10^{-6}$
T11	118	4.64 hrs	$4.49 * 10^{-6}$

Note that reliability criteria do not exist for all the load points considered, and evaluation of these results are based on the judgment of the designers and the users. Personnel from the relocation project team have examined these results and have judged them to be acceptable.

4. CONCLUSIONS

A reliability assessment of the power supply at Clarkson has been carried out. The estimated reliability indices were judged to be acceptable by the project relocation department. These figures will form the input to the next phases of the reliability analysis of the Control Center facilities.

REFERENCES

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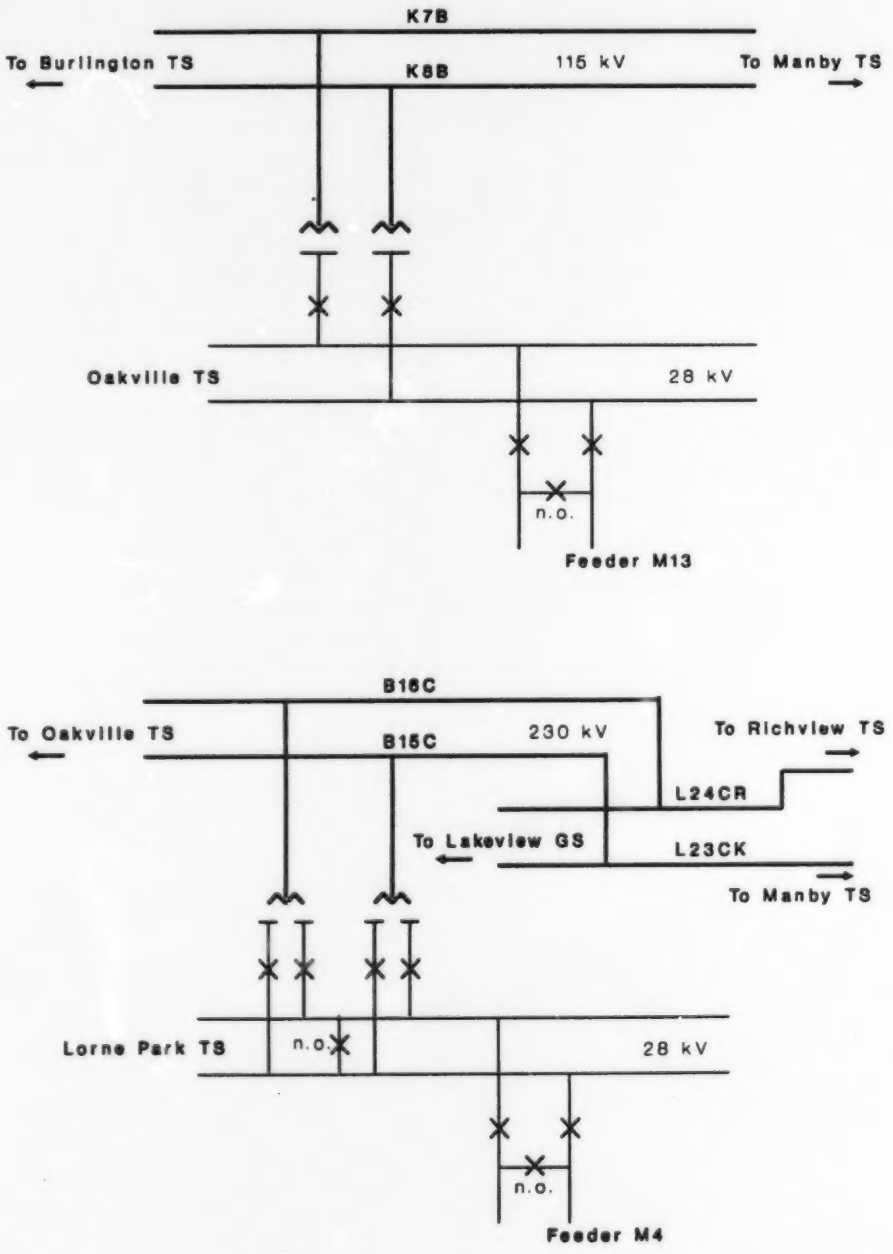

Figure 1 - BES Supply to Clarkson

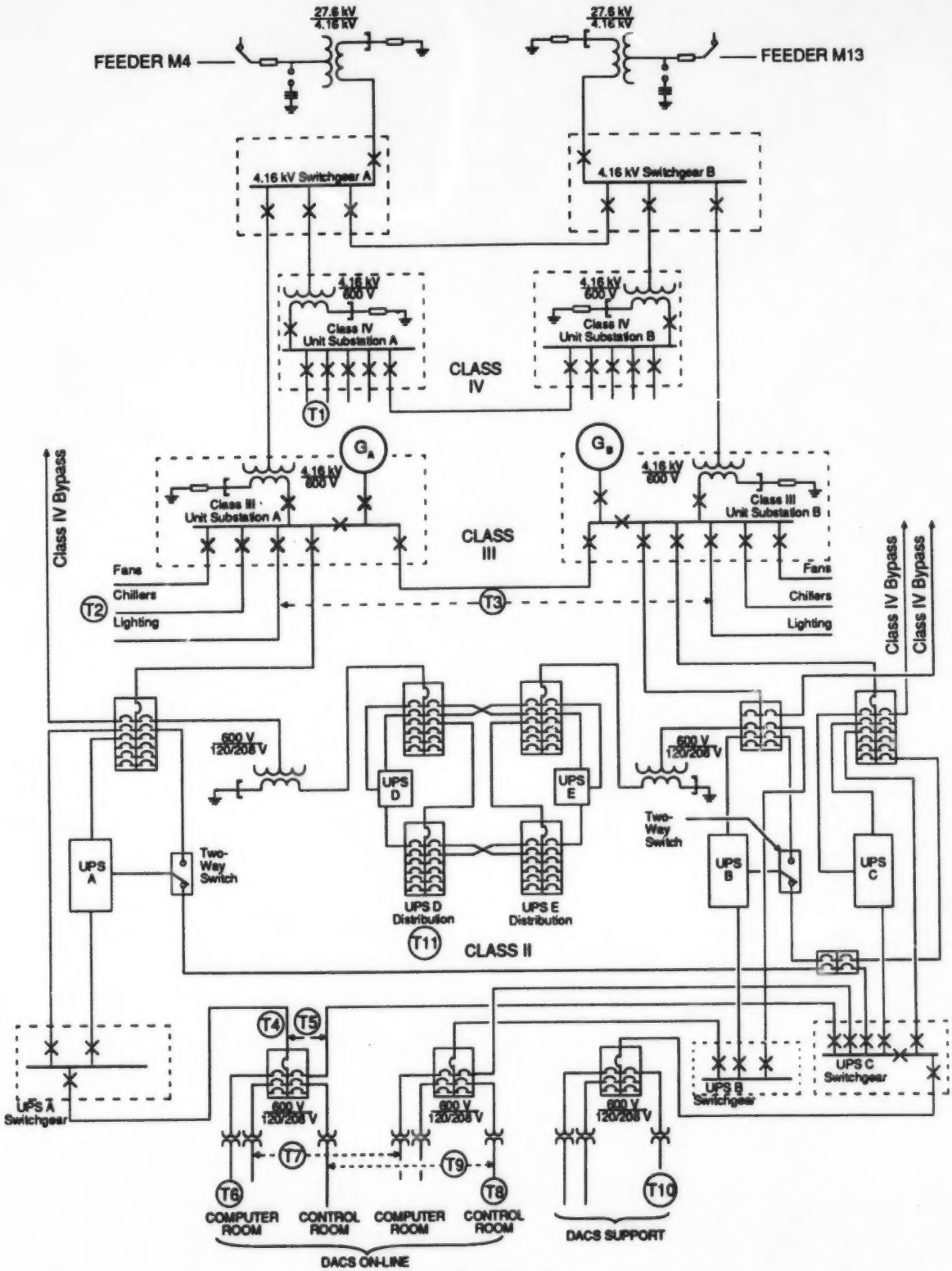

FIGURE 2
CLARKSON SCC

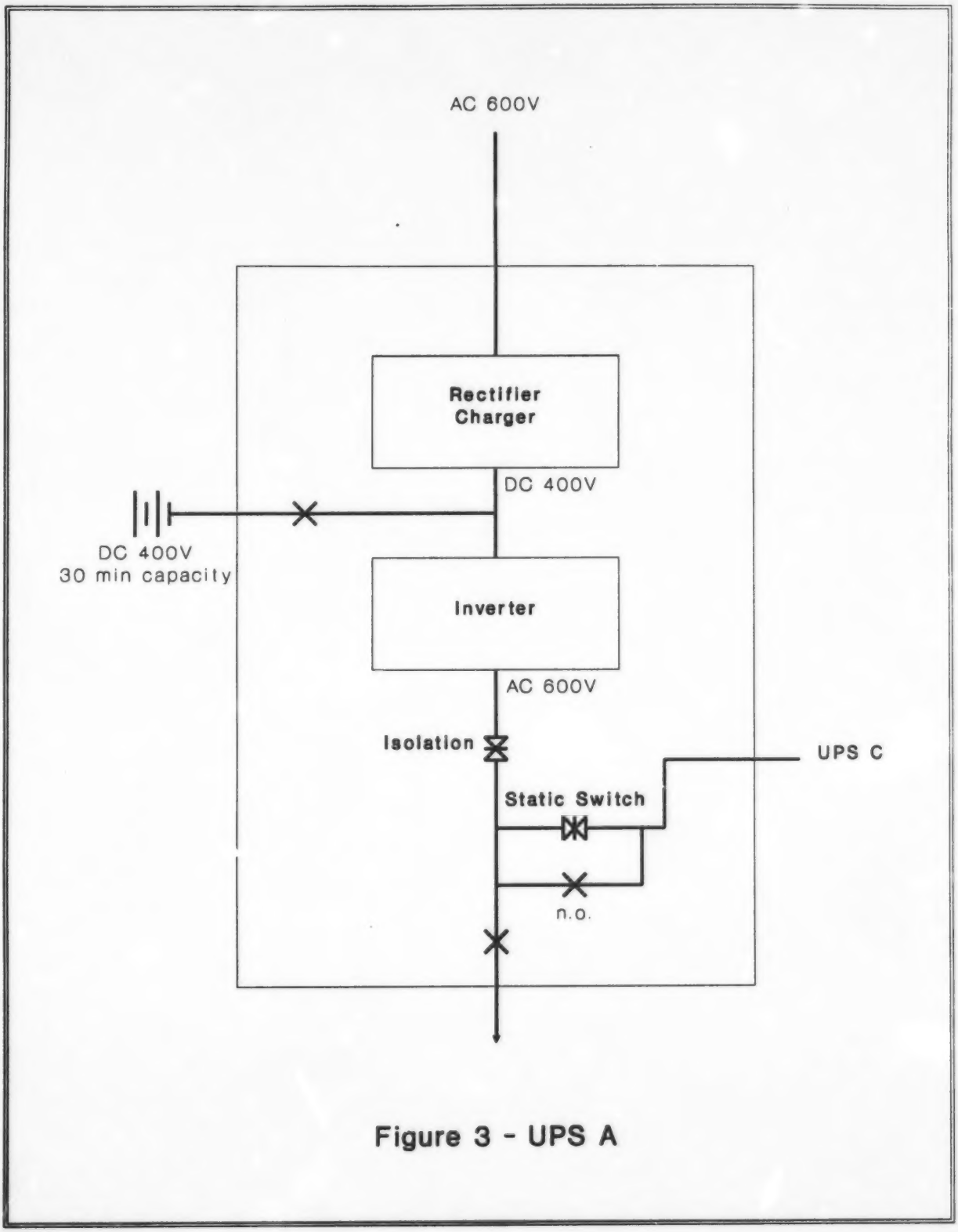

Figure 3 - UPS A

RESULTS

The results of the analysis are presented in the following tables.

Table 1 : Class IV Loads

Table 2 : Class III Loads - Case 1 (one element)

Table 3: Class III Loads - Case 2 (both elements)

Table 4 : UPS A (output of UPS A switchgear)

Table 5 : UPS A (OR) UPS C (Input to a computer distribution frame)

Table 6 : Computer room - Case 1 (Loss of one of the four feeds)

Table 7 : Computer room - Case 2 (Loss of one feed from each distribution frame)

Table 8 : Control room - Case 1 (Loss of one of the two feeds)

Table 9 : Control room - Case 2 (Loss of both feeds)

Table 10 : DACS Support

Table 11 : UPS D and UPS E Loads

TABLE 1

CLASS IV LOADS

Failure Criterion: Loss of power to any given load supplied by one element at the Class IV level.

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Momentary			
Element A	0.155	1.7 sec	$0.347 * 10^{-6}$
Element B	0.133	2.8 sec	$0.668 * 10^{-6}$
Forced Outages - Sustained	62.7	4.93 hrs	$8.98 * 10^{-6}$
Forced Outage of Backup during Maintenance (see comment 3)	2.20	1.34 hrs	$69.5 * 10^{-6}$
Total - Sustained	2.13	1.46 hrs	$78.5 * 10^{-6}$

Comments:

1. Class IV feeds mostly non-essential loads (office loads etc.). It is assumed that there is no redundancy and the loss of power at a breaker feed at a Class IV substation constitutes a failure.

2. Events contributing significantly to the failure frequency and/or probability include:
   (a) the loss of power at the main feeders (Lorne Park or Oakville)
   (b) the failure of the Class IV substation bus
   (c) the failure of the Class IV substation breaker.

3. Maintenance of the Class IV substations are not included.

TABLE 2

CLASS III LOADS - CASE 1

Failure Criterion: Loss of power to any given load supplied by one element at the Class III level.

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Momentary			
Element A	0.154	1.8 sec	$0.366 * 10^{-6}$
Element B	0.133	2.9 sec	$0.686 * 10^{-6}$
Forced Outages - Sustained	208	8.00 hrs	$4.38 * 10^{-6}$
Forced Outage of Backup during Maintenance (see comment 4)	300,000	4.00 hrs	$0.002 * 10^{-6}$
Total - Sustained	208	8.00 hrs	$4.39 * 10^{-6}$

Comments:

1. Class III feeds critical loads such as air conditioning.
2. On-site standby generation is available for back up.
3. Events contributing significantly to the failure frequency and/or probability include:
   (a) the loss of power at one or both the feeders (Lorne Park and Oakville)
   (b) the failure of the Class III substation bus
   (c) the failure of the Class III substation breaker.
4. Maintenance of the class III substations are not included.

TABLE 3

CLASS III LOADS - CASE 2

Failure Criterion: Loss of power to any given load supplied by both elements at the Class III level.

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Momentary	100	1.0 min	$19.0 * 10^{-9}$
Forced Outages - Sustained	$2 * 10^{7}$	3.84 hrs	$0.02 * 10^{-9}$
Forced Outage of Backup during Maintenance	200,000	4.00 hrs	$2.00 * 10^{-9}$
Total - Sustained	200,000	4.00 hrs	$2.02 * 10^{-9}$

Comments:

1. At the Class III level, there is full redundancy in most cases and the two elements feed identical loads. This case analyses the case where both elements and both the diesel generators fail.

TABLE 4

UPS A

Failure Criterion: Loss of power at the output of UPS A metalclad switchgear

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages · Sustained	75.5	7.62 hrs	$11.5 * 10^{-6}$
Forced Outage of Backup during Maintenance (see comment 4)	60,000	4.00 hrs	$0.008 * 10^{-6}$
Total · Sustained	75.4	7.62 hrs	$11.5 * 10^{-6}$

Comments:

1. All the UPS systems are backed up by a battery with a capacity of 30 minutes at full load.

2. If the UPS A inverter fails, an automatic bypass switch transfers control to UPS C.

3. Events contributing significantly to the failure frequency and/or probability include:
   (a) the failure of the 600V metalclad switchgear bus
   (b) the failure of the 600V metalclad switchgear breaker.

4. Maintenance of the UPS A metalclad switchgear is not included.

TABLE 5

UPS A (OR) UPS C

Failure Criterion: Loss of power at the input to a computer distribution frame supplying the computer and control rooms

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Switching	75.5	10.0 min	$0.252 * 10^{-6}$
Forced Outages - Sustained	74000	3.90 hrs	$0.006 * 10^{-6}$
Forced Outage of Backup during Maintenance	48000	3.89 hrs	$0.009 * 10^{-6}$
Total	75.3	10.6 min	$0.267 * 10^{-6}$

Comments:

1. The computer and control rooms are supplied by two computer distribution frames fed by UPS A and UPS B metalclad switchgears respectively. In case of failure of supply from either of the switchgears, a manual transfer is made to UPS C switchgear. This case examines the logical "OR" of the two inputs UPS A and UPS C, ie, the possibility of loss of power to a distribution frame.

TABLE 6

COMPUTER ROOM - CASE 1

Failure Criterion: Any interruption to any of the four feeds to the computer room

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Switching	37.7	10.0 min	$0.504 * 10^{-6}$
Forced Outages - Sustained	35.7	24.8 hrs	$79.3 * 10^{-6}$
Forced Outage of Backup during Maintenance	24000	3.89 hrs	$0.019 * 10^{-6}$
Total	18.3	12.8 hrs	$79.8 * 10^{-6}$

Comments:

1. There are four lines available for the computer room fed via two separate computer distribution frames. Loss of power to any one of the four feeds is evaluated here.

2. Events contributing significantly to the failure frequency and/or probability include:
   (a) the failure of any of the UPS systems
   (b) the failure of a 600/120/208V transformer
   (c) the failure of the computer distribution frame bus
   (d) the failure of the computer distribution frame breaker.

TABLE 7

COMPUTER ROOM - CASE 2

Failure Criterion: Loss of power to two of the four feeds to the computer room, the two feeds in question being fed via two separate computer distribution frames.

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Switching	700,000	10.0 min	$0.026 * 10^{-9}$
Forced Outages - Sustained	1,600,000	11.8 hrs	$0.828 * 10^{-9}$
Total	500,000	3.76 hrs	$0.854 * 10^{-9}$

Comments:

1. There are four lines available for the computer room fed via two separate computer distribution frames. Loss of two of the feeds is particularly critical, ie, recovery is not possible via a simple reconfiguration, when the two feeds are being fed via two separate distribution frames. This event is analyzed here.

2. There is considerable redundancy available in the system and thus most failure events are cleared by switching. Thus, the probability of the above event is very small.

TABLE 8

CONTROL ROOM - CASE 1

Failure Criterion: Any interruption to any of the two feeds to the control room

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Switching	37.7	10.0 min	$0.504 * 10^{-6}$
Forced Outages - Sustained	65.7	23.4 hrs	$40.7 * 10^{-6}$
Forced Outage of Backup during Maintenance	24000	3.89 hrs	$0.019 * 10^{-6}$
Total	23.9	8.65 hrs	$41.3 * 10^{-6}$

Comments:

1. There are two lines available for the control room fed via two separate computer distribution frames. Loss of power to any one of the two feeds is evaluated here.

2. Events contributing significantly to the failure frequency and/or probability include:
   (a) the failure of any of the UPS systems
   (b) the failure of a 600/120/208V transformer
   (c) the failure of the computer distribution frame bus
   (d) the failure of the computer distribution frame breaker.

TABLE 9

CONTROL ROOM - CASE 2

Failure Criterion: Loss of power to both the feeds to the control room

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Switching	1,400,000	10.0 min	$0.014 * 10^{-9}$
Forced Outages - Sustained	3,200,000	11.7 hrs	$0.415 * 10^{-9}$
Total	1,000,000	3.66 hrs	$0.429 * 10^{-9}$

Comments:

1. There are two lines available for the control room fed via two separate computer distribution frames. Loss of both the feeds is evaluated here.

2. There is considerable redundancy available in the system and thus most failure events are cleared by switching. Thus, the probability of the above event is very small.

TABLE 10

DACS SUPPORT

Failure Criterion: Loss of power to any one of the three feeds to the DACS Support system (fed primarily by UPS C)

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Sustained	26.0	17.0 hrs	$74.8 * 10^{-6}$
Forced Outage of Backup during Maintenance (see comment 3)	24,000	4.00 hrs	$0.02 * 10^{-6}$
Total	26.0	17.0 hrs	$74.8 * 10^{-6}$

Comments:

1. The support services are fed by three lines and it is assumed that the loss of any one of these lines constitutes a failure.

2. Events contributing significantly to the failure frequency and/or probability include:
   (a) the failure of the UPS C system
   (b) the failure of the 600/120/208V transformer
   (c) the failure of the computer distribution frame bus
   (d) the failure of the computer distribution frame breaker.

3. Maintenance of the UPS C switchgear is not included.

TABLE 11

UPS D AND UPS E LOADS

Failure Criterion: Loss of power for the loads fed by UPS D and UPS E

Reliability Evaluation:

Outage Category	MTBF (years)	Mean Time to Restore	Probability of Outage
Forced Outages - Switching	278	10 min	$0.07 * 10^{-6}$
Forced Outages - Sustained	208	8.00 hrs	$4.38 * 10^{-6}$
Forced Outage of Backup during Maintenance	15,000	4.62 hrs	$0.04 * 10^{-6}$
Total	118	4.64 hrs	$4.49 * 10^{-6}$

Comments:

1. UPS D and E feed several critical loads such as control power for all the breakers, emergency lighting and essential telemetry.

2. The UPS systems are backed up by a battery with a capacity of 30 minutes.

3. It is assumed that loss of power at the computer distribution frame is a failure and any redundancies at the load level are not accounted for.

4. Events contributing significantly to the failure frequency and/or probability include:
   (a) the failure of the 600V computer distribution frame bus
   (b) the failure of the 600V computer distribution frame breaker
   (c) the failure of the 600/120/208V transformer
   (d) the failure of the computer distribution frame bus
   (e) the failure of the computer distribution frame breaker.

APPENDIX A

OUTAGE DATA

This Appendix lists the outage data used in this study. Most of the data were obtained from References 2, 3 and 4.

Transmission Lines
(per 100 km)

Component or Mode	Outage Frequency (/yr)		Outage Duration (hrs)
	Normal Weather	Adverse Weather	
230kV			
Permanent	0.04	4.23	11.2
Temporary	0.04	24.67	0.1067
Transient	0.05	51.08	0.0042
115kV			
Permanent	0.15	17.31	12.6
Temporary	0.22	112.49	0.075
Transient	0.48	38.32	0.0042
Common mode 230kV			
Permanent	0.009	2.15	11.2
Temporary	0.0	10.75	0.1067
Transient	0.0	9.89	0.0042
Common mode 115kV			
Permanent	0.0	0.69	12.6
Temporary	0.014	22.08	0.075
Transient	0.0	68.99	0.0042
28kV Feeder	0.1436	0.1436	1.258
M4 Transient*	5	5	0.0003
M13 Transient*	3	3	0.0003

* Note: These figures are not system averages, but are based on component specific data provided to the SCC Relocation Department by the Regions Branch. Also, the numbers refer to the whole feeders, and are not per 100km.

Transformers

Component or Mode	Outage Frequency (/yr)		Outage Duration (hrs)
	Normal Weather	Adverse Weather	
230kV/28kV	0.114	0.114	142
115kV/28kV	0.114	0.114	142
28kV/4.16kV	0.013	0.013	50
4.16kV/600V	0.0053	0.0053	50
600V/120V	0.0028	0.0028	50

Bus Sections

Component or Mode	Outage Frequency (/yr)		Outage Duration (hrs)
	Normal Weather	Adverse Weather	
230kV or 115kV			
Permanent	0.012	2.817	13.3
Temporary	0.008	0.352	0.355
28kV	0.0649	0.0649	8
4.16kV	0.0167	0.0167	15
600V	0.0012	0.0012	8
120V	0.0012	0.0012	8

Circuit Breakers

Component or Mode	Outage Frequency (/yr)	Outage Duration (hrs)
230kV	0.0074	249.6
115kV	0.0025	249.6
4.16kV	0.0082	10
600V	0.0036	8
120V	0.0036	8

UPS components
(600V and 120V)

Component or Mode	Outage Frequency (/yr)	Outage Duration (hrs)
Rectifier	0.044	12
Inverter	1.25	8
Battery	0.0014	8
Static Switch	0.0036	8
Breaker	0.0036	8

Maintenance Data

Component or Mode	Outage Frequency (/yr)	Outage Duration (hrs)
Transmission Line	0.0056/km	114
Line Terminal	0.3274	72.9
Circuit Breaker	0.1933	82.0
Bus Section	0.2862	73.6
Tap Transformer	0.4507	98.3
Class IV / III Substation	1.0	8.0
Metalclad Switchgear	1.0	8.0
UPS	1.0	8.0

Miscellaneous

Probability of a breaker failing to open = 0.0005

Probability of a normally open breaker failing to close = 0.0005

Time for an open breaker to close
- auto (Class IV tie) = 5 sec
- auto (Class III tie) = 10 sec

Time for an open breaker to close
- manual = 10 min

Probability of generator start failure = 0.02

Time for the generator to be on-line = 1 min